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Assessment of Gilbert Bay's Marine Protected Area Indicator Monitoring

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

In 2005, Gilbert Bay, Labrador was given Marine Protected Area (MPA) status under Canada's *Oceans Act* to protect a local population of Atlantic Cod and its habitat. The population of Atlantic Cod living in Gilbert Bay has had continuous science monitoring since 1998. MPA monitoring was first reviewed in 2009, and five existing monitoring indicators were determined sufficient to provide population trends important to evaluate the MPA conservation objectives. This assessment provides an update of those indicator data. Monitoring information indicates that the Gilbert Bay cod population is at a low level of abundance compared to its abundance in 1998. Shortcomings pertaining to some monitoring indicators are identified, specifically with respect to the sampling of pelagic juveniles. Observed changes within the Gilbert Bay fish community and harvest levels of Northern cod outside the MPA are presented. Preliminary results from related ongoing research, in addition to existing indictor data, are provided to suggest that Gilbert Bay cod are locally adapted and that migratory Northern cod overlap spatially and temporally with the distribution of Gilbert Bay cod. Adapting the existing monitoring program, and related research, to focus on improving effectiveness of the MPA to meet conservation objectives could be warranted; however, changes could impact the consistency of the long-term MPA monitoring program.

Évaluation de la surveillance des indicateurs de la zone de protection marine de la baie Gilbert

RÉSUMÉ

En 2005, la baie Gilbert, au Labrador, a été désignée comme une zone de protection marine (ZPM) aux termes de la *Loi sur les océans* afin de protéger une population locale de morue franche et son habitat. La population de morue franche vivant dans la baie Gilbert fait l'objet d'une surveillance scientifique continue depuis 1998. La surveillance de la ZPM a été examinée pour la première fois en 2009 et il a été déterminé que, parmi les indicateurs de surveillance actuels, cinq indicateurs fournissent des données sur les tendances de la population qui sont importantes pour l'évaluation des objectifs de conservation de la ZPM. La présente évaluation fournit une mise à jour des données de ces indicateurs. Les renseignements sur la surveillance indiquent que l'abondance de la population de morue de la baie Gilbert est faible par rapport à son abondance en 1998. Des lacunes relatives à certains indicateurs de surveillance ont été relevées, notamment en ce qui a trait à l'échantillonnage des juvéniles pélagiques. De plus, les changements observés dans la communauté de poissons de la baie Gilbert et les niveaux de prises de morue du Nord à l'extérieur de la ZPM sont présentés. Les résultats préliminaires des recherches connexes en cours et les données sur les indicateurs actuels laissent supposer que la morue de la baie Gilbert est adaptée localement et que la voie de migration de la morue du Nord chevauche, sur le plan spatial et temporel, l'aire de répartition de la morue de la baie Gilbert. Il pourrait être justifié d'adapter le programme de surveillance existant et les recherches connexes afin de mettre l'accent sur l'amélioration de la capacité de la ZPM à atteindre les objectifs de conservation. Toutefois, des changements pourraient avoir une incidence sur l'uniformité du programme de surveillance de la ZPM à long terme.

INTRODUCTION

The conservation objective of the Gilbert Bay Marine Protected Area (MPA), established in 2005, is to protect and conserve the genetically distinctive population of Atlantic Cod (*Gadus morhua*) which resides there, along with its habitat (Canada Gazette 2005). As a species, the Atlantic Cod is represented by many separate populations of fish. Populations are often labeled stocks for management purposes, and enable harvesting limits based on biological characteristics of a single stock. For example, the Northern cod stock area includes Northwest Atlantic Fisheries Organization (NAFO) management Divisions (Divs.) 2J, 3K, and 3L. Although Atlantic Cod in this region are similar and are collectively known as Northern cod, there is more than one population of cod within this large area. Atlantic Cod in Gilbert Bay are a distinct population of Atlantic Cod within the Northern cod stock Div. 2J.

Aspects of the Gilbert Bay MPA monitoring program have been conducted since 1998. The monitoring program was last reviewed in 2009 (Fisheries and Oceans Canada [DFO] 2010). A related Canadian Science Advisory Secretariat (CSAS) research document, titled "Gilbert Bay Marine Protected Area science indicator monitoring" (Morris and Green 2010) provided scientific information for the review. That process identified existing indicators as being sufficient to monitor the MPA against its conservation objectives. Since then, MPA monitoring has continued and provided an important contribution to MPA management. However, several biological and management changes that may affect the ability of the Gilbert Bay MPA to meet its conservation objectives have arisen since the last monitoring review.

Declines in the Gilbert Bay cod population (Morris and Green 2014), increases in the abundance of other fish species, and an increase in the abundance of Northern cod and its commercial fishery have occurred in recent years. These changes have prompted an updated assessment of the Gilbert Bay MPA and its monitoring program to ensure that management decisions have relevant scientific information. Should management changes be adopted, prudent consideration is needed prior to changing the long-term monitoring program. Although adaptive management should improve MPA effectiveness, most MPA management processes have finite resources and therefore implementing adaptive management could potentially impact existing research and monitoring activities. Changes to a monitoring program could affect consistency and comparability of data with negative long-term consequences. This report updates current monitoring and research information for consideration in the context of potential adaptive management action in the Gilbert Bay MPA.

METHODS

The Gilbert Bay MPA monitoring program has 19 years of continuous data. Seven years of data have been collected since the 2009 review. Morris and Green (2010) described the Gilbert Bay monitoring program, its sampling methods, and data collected for each of five indicators listed in this report.

The five indicators currently used to monitor the Gilbert Bay MPA are:

1. Recruitment of age 0 pelagic juveniles. Data for this indicator are collected by horizontal ichthyoplankton net tows. These catch cod eggs in spring and small pelagic juvenile cod in summer, as well as other plankton.
2. Recruitment of ages 2, 3, and 4 year old Atlantic Cod. Data for this indicator are collected by angling, and the size data partitioned based on previous otolith aging, to investigate relative abundance of year classes.

3. Research Catch per Unit Effort (CPUE). Catch and fishing effort (time) during angling are recorded for each fishing location, and fish lengths are recorded. Data are partitioned based on the commercial size of Northern cod typically caught near Gilbert Bay. The recapture of Gilbert Bay cod tagged inside the MPA and recaptured outside the MPA during index fisheries is used to determine harvest size selectivity in the Northern cod fishery near Gilbert Bay (see Morris et al. 2003).
4. Movement and migration patterns. Data from acoustically tagged Gilbert Bay cod are collected by acoustic telemetry hydrophones distributed throughout the home range of Gilbert Bay cod, and analyzed periodically (see Morris and Green 2014; Morris et al. 2014).
5. Catch information from commercial and other fishing activities. Landings data from various fisheries are collected by DFO Statistics Branch and applied to harvesters within the home range of Gilbert Bay cod.

RESULTS

INDICATOR 1: RECRUITMENT OF AGE 0 PELAGIC JUVENILES

Sampling for this indicator has included Atlantic Cod eggs and pelagic juveniles, collected in June and August respectively, at important spawning locations in MPA zone 1a (Figure 1). Typically, egg density ranged from 40-65 eggs/m^3 and has not correlated with year class strengths sampled at older ages by angling. Therefore egg density has not been considered an important indicator of population trend. Samples from 1999 to 2011 were consistently processed; however, samples from 2012 to 2015 remain unprocessed. Until 2016, field observations of samples did not suggest obvious changes in egg abundance. 2016 was the first year that no cod eggs were observed visually in the field while collecting plankton samples. When samples were processed in the laboratory remarkably few cod eggs (1 egg/m^3) were found (Figure 2). Efforts have resumed to measure cod egg abundance for those years with unprocessed samples.

Plankton sampling in August has targeted pelagic juvenile cod (Figure 3). Typically this sampling catches fish less than 30 mm total length (TL). Occasionally fish as large as 45 mm TL are caught. Although correlations have not been good between pelagic juveniles and older year classes in Gilbert Bay, the expectation has been that the abundance of pelagic juveniles could inform year class strength. Pelagic juvenile Atlantic Cod that are smaller than 35 mm are similar in appearance to Rock Cod (*Gadus ogac*). In recent years, a small number of larger sized cod in plankton net catches were identified as Rock Cod based on visually observed characteristics. The species identification of small pelagic cod must be resolved if pelagic juvenile abundance is to be used as an indicator of year class strength.

INDICATOR 2: RECRUITMENT OF AGES 2, 3, AND 4 YEAR OLD GILBERT BAY COD

Estimation of fish age based on length frequency distribution works well for Gilbert Bay cod at smaller sizes (TL < 30 cm and ages 2-4 yr.), but lengths-at-age overlap considerably after 5 years of age. Since Gilbert Bay cod are at a very low level of abundance, lethal sampling was not conducted to obtain additional otolith derived ages. An existing length at age relationship based on earlier Gilbert Bay data (Morris and Green 2014) was used to support length frequency mode-based age interpretations.

To estimate the relative strength of year classes based on length frequency sampling, we analyzed the relative abundance of fish expected to be ages 2, 3 and 4 based on interpretation

of length frequency data. The occurrences of both strong and weak year classes are identifiable (Figure 4). A consistent positive or negative value (relative to the mean), across successive years suggests a relatively strong or weak year class respectively. For example, based on this criteria noticeably weak year classes include 1997, 2003, 2010, and 2011 while 2006 and perhaps 2013 are strong. The 2013 and more recent year classes cannot be effectively assessed at this time because of limited data. For example, the year class of fish produced in 2013 will not be sampled as age 4 until 2017.

INDICATOR 3: RESEARCH CATCH PER UNIT EFFORT (CPUE)

The CPUE data from angling has provided a fairly consistent decreasing trend over time. This trend is considered to reflect changes in the relative abundance of Gilbert Bay cod, and suggest that Gilbert Bay cod has declined significantly over time. In 2016, sampling caught one fish per hour of fishing compared to nearly six fish per hour of fishing in 1998 (Figure 5). Large sexually mature and commercial size fish, those 45 cm and larger, are less than 10% of that caught in 1998 (Figure 6). Since 2010, the average size of fish sampled on spawning grounds during the spawning season was at or below the size of female sexual maturation (Figure 7). Length frequency distributions sampled in 1998 and 2016, standardized by effort, illustrates differences in population demographics, with particularly fewer fish at larger sizes (Figure 8).

Research sampling in Gilbert Bay has consistently sampled MPA zone 1A since 1998. For the first eight years of sampling (1998 to 2005), at least one Gilbert Bay cod was caught during each fishing period in spring. Beginning in 2006, research sampling has indicated an increasing proportion of fishing periods (30 minutes minimum) without any catch (Figure 9), indicating a much lower availability of fish.

Along with an increase in zero-catch sets, angling has indicated an increased abundance of other fish species, including Smooth Flounder (*Liopsetta putnami*), sculpin (*Myoxocephalus sp.*, and *Hemitripterus americanus*), and Rock Cod (*Gadus ogac*), in MPA zone 1a (Figure 10). Angling in this area from 1998 to 2006 caught only Gilbert Bay cod. Since 2007, sampling has caught increasing numbers of each of these additional species. Most often, individuals of these species have been small in size and probably sexually immature, with the exception of the flounder. Only in 2015 and 2016 have sexually mature flounder and Rock Cod been caught. Sexually ripe sculpin have not been observed, possibly because their annual spawning period does not overlap with the timing of Gilbert Bay MPA monitoring. The increasing occurrence of sexually mature individuals indicates an increased prevalence in this area of Gilbert Bay.

INDICATOR 4: MOVEMENT AND MIGRATION PATTERNS

Movement information determined based on acoustic tracking of marked individuals has contributed to Gilbert Bay MPA Monitoring in the past, and is still a part of MPA research. This research is an important part of understanding MPA effectiveness, and interpreting indicator data, particularly as new information becomes available. Relevant research results are discussed under the "supporting research" section appended to this report.

INDICATOR 5: CATCH INFORMATION FROM COMMERCIAL AND OTHER FISHING ACTIVITIES

The Northern cod fishery within the known home range of Gilbert Bay cod has continued and removals have increased in recent years (Figure 11). The largest decline in research CPUE was observed between 2007 and 2008. Since 2008, relatively few commercial sized fish have been caught during research sampling. The number of large Gilbert Bay cod that are available to the fishery is low because the overall population of mature cod is currently at a low level. However,

those large cod in the population are of migratory size and most likely to leave the MPA in summer, and therefore available to commercial fishing outside the MPA. Table 1 provides information describing the number of harvesters, quota, and timing of the Northern cod fishing season.

DISCUSSION

The Gilbert Bay MPA monitoring program effectively tracks important biological changes to the local cod population, and potential threats. Monitoring information suggests that Gilbert Bay cod are at a low abundance and face increasing anthropogenic (fishing) and non-anthropogenic (fish community changes) threats. Gilbert Bay cod and Northern cod mix in areas immediately outside the MPA (Morris and Green 2014). The removal of Gilbert Bay cod that occurs during fishing near the MPA (Morris et al. 2003; Morris and Green 2014), and the proportion of Gilbert Bay cod to Northern cod captured, depends on the timing and location of fishing, allowable harvests, as well as the abundance of cod available (both Gilbert Bay and Northern cod).

The Gilbert Bay MPA process was initiated because fishery removals threatened the population. The 2007 fishing season occurred in July-August, a period when migratory Gilbert Bay cod are most likely outside the MPA. Landings that year were relatively high but the abundance of Northern cod was low suggesting that the impact on Gilbert Bay cod was likely very large. The abundance of Gilbert Bay cod sampled in 2007 and 2008 measured by CPUE monitoring, did show the largest decline observed over the 19-year time series. Management changes to the timing and location of fishing have been suggested each year since 2008, to reduce captures of Gilbert Bay cod. Unfortunately, during 2016 the Northern cod fishing season within the vicinity of Gilbert Bay included higher quotas (i.e. removals) and an earlier start date.

In addition to this anthropogenic threat, there was continuing evidence that species other than Gilbert Bay cod are increasing in abundance at key overwintering and spawning areas within the MPA. The cause(s) and future extent of these changes in distribution patterns and abundances of other fish species are unknown. However, results from other MPA research have shown that an increase in large predators can reduce the number and abundance of other species, particularly those smaller in size (Edgar and Stuart-Smith 2009).

The purpose of sampling cod eggs as part of MPA monitoring and research was to identify the timing and location of spawning, identify local retention of eggs near spawning areas, and compare the relative abundance of eggs with spawner biomass. The timing and location of spawning suggests that Gilbert Bay cod are locally adapted to its environmental conditions and are reproductively separated from other cod populations (Morris 2013). The correlation of egg abundance with spawner biomass has been poor, but the density of cod eggs collected from 1998 to 2011 has been higher than that sampled for other populations (Anderson and deYoung 1995; Morris 2013). In 2016 however, the density of cod eggs sampled was low compared to other years of sampling. It is unknown whether this was due to a reduced number of spawners, increased egg predation, changed environmental conditions or a combination of these factors. Regardless of the reason, this is a cause for concern.

The abundance of pelagic juvenile cod has not produced consistent correlations with year class abundance sampled at older ages. Genetic data from 2012 and 2015 samples indicate that Rock Cod (*Gadus ogac*) are sampled in addition to Gilbert Bay cod. Within the size range of pelagic cod typically sampled (~1 mm to 40 mm), Atlantic Cod are visually similar to Rock Cod and could be misidentified. At larger sizes in this range the lateral line and some colouration differences exists, which has suggested that some pelagic fish sampled in Gilbert Bay in 2016 were Rock Cod. At this time it is not known whether Rock Cod have become more prevalent in pelagic juvenile sampling, however, archived samples can be used to examine this with genetic

analysis. Correct species identification of pelagic juveniles is required to utilize this indicator for monitoring.

Spring sampling periods during 2006-09 show an increase in the frequency of zero-catch per fishing set. Concomitantly there was an increase in catch of fish species other than Gilbert Bay cod. Previous to this period, eight years of sampling occurred before any zero-set catches, and a decade of sampling before other fish species were observed in angling catches in MPA zone 1a. These changes are thought to be ecologically important since MPA zone 1a is the primary overwintering and spawning area for Gilbert Bay cod. Along the coast of Labrador, bays typically support sculpin, flounder and Rock Cod, but not local populations of Atlantic Cod. The ecological processes associated with different species interactions are poorly understood, and the changes observed in Gilbert Bay question the ability of Gilbert Bay cod to persist should the Gilbert Bay fish community become more like that of neighbouring bays. A study by Edgar and Stuart-Smith (2009) supports the hypothesis that trophic cascades can occur in response to changing species demographics, in that an increasing density of large fish will affect smaller prey populations. In other regions, such as the Gulf of Maine and along the north east coast of Newfoundland, evidence suggests that overfishing resulted in the disappearance of resident Atlantic Cod populations (Myers 1997; Ames 2004).

It is known that Gilbert Bay cod spend time outside existing MPA boundaries where they are susceptible to fishery removals (Morris et al. 2003; Morris and Green 2014; Morris et al. 2014). The fishery for Northern cod in the vicinity of Gilbert Bay since 1998 has varied in size, timing, and duration. The fishery for Northern cod will have the lowest impact on Gilbert Bay cod when most Gilbert Bay cod are inside the MPA, typically from October to May (Morris and Green 2014). Migratory Gilbert Bay cod usually move out of Gilbert Bay during June and return during September (Morris et al. 2014), but the exact timing is likely dependent on environmental conditions, food availability, and population demographics.

MANAGMENT CONSIDERATIONS

The Gilbert Bay MPA conservation objective is to protect the local cod population and its habitat. This objective has merit, but does not include any specific metrics to determine whether the MPA is an effective management tool. Selection of reference points (i.e. a level of abundance), based on existing information, could improve the ability to evaluate MPA effectiveness and management decision making.

Declines in abundance have led to adaptive management considerations, which have been discussed since 2008, including changes to fishing locations and timing of the commercial fishery (Morris and Green 2014). Few such adaptive management changes have been implemented. MPA boundary changes were considered unacceptable, based on consultations with the fishing industry and MPA regulators. Discussion to implement changes to the timing of the fishery has been positive. However, the season opening dates have changed very little, and the fishing season was extended in 2016 in response to a continued Northern cod recovery. Should the allowable catch of Northern cod continue to increase, or should the fishing season continue to lengthen into the summer period, increased removals of Gilbert Bay cod will occur unless other adaptive management activities are implemented.

The use of cod pots has been suggested as a potential adaptive management strategy to help conserve Gilbert Bay cod. Cod pots, or other live trapping methods, in the vicinity of Gilbert Bay might be used to harvest Northern cod and allow the live-release of any by-catch of Gilbert Bay cod. This presupposes that Gilbert Bay cod could be distinguished by fishers from Northern cod based on differences in colouration. If such practices were implemented, they have the potential to reduce the impact of the Northern cod fishery on Gilbert Bay cod.

The presence of adaptive diversity is a principle consideration in the management and conservation of exploited species (Hilborn 2003; Schindler et al. 2010). Empirical evidence indicates that Gilbert Bay cod are different from other Atlantic Cod populations, genetically and behaviourally. Some of the first genetic information describing Northern cod population structure, based on microsatellite data, identified Gilbert Bay cod as being distinct (Ruzzante et al. 2000; Beacham 2002), but the population's local adaptations to its environment were poorly understood at that time. It became known from a behavioural perspective that the population is separated from other cod populations (Green and Wroblewski 1999; Morris and Green 2002; Morris et al. 2014) and there was a high potential for adaptive divergence. Observed behavioural differences, particularly its overwintering location, timing and location of spawning, shallow water residency, and exposure to sub-zero temperatures for a six-month period, suggest local adaptations to its environment (Morris 2013; Morris et al. unpublished data). Most other Atlantic Cod populations experience considerably more degree days per year and higher average temperatures than Gilbert Bay cod (see Robichaud and Rose 2004; Righton et al. 2010). Genomic analysis has identified gene-associated polymorphisms for which allele frequencies show temperature-associated clines among otherwise genetically distinct Atlantic Cod populations, testing positive for genetic signatures of selection (Bradbury et al. 2010). Recent genomic techniques, analyzing single nucleotide polymorphisms associated with genes, clearly identify and distinguish Gilbert Bay cod from others with 100% accuracy (Bradbury et al. 2013). Arguably all genetically distinct populations are somehow locally adapted. However, measuring potential contributions of intraspecific population diversity towards long-term survival of an associated metapopulation is difficult.

The Northern cod stock was affected by a regime shift in the early-1990s, with concomitant restructuring of the system including a collapse in groundfish stocks that resulted from synergistic climate and anthropogenic forces (Buren et al. 2014). The Gilbert Bay cod population however thrived and rebuilt during this same period, as evidenced by a wide range of year classes and high abundance sampled in 1998 after six years of fishing moratoria (Morris and Green 2014). That Gilbert Bay cod flourished while the neighbouring and overlapping Northern cod population experienced high mortality, suggests an example where intraspecific diversity can act as a buffer against changed environment conditions.

CONCLUSION

In summary, the Gilbert Bay MPA monitoring program to date has described important trends in the Gilbert Bay cod population. Monitoring information indicates that the Gilbert Bay cod population is at a low level of abundance compared to its abundance in 1998. Strength of the existing monitoring is the collection and integration of evidence from different sources of information, over a 19-year period. These long-term data could be used to establish reference points to evaluate MPA effectiveness. Shortcomings pertaining to the species level identification of pelagic juveniles could be improved to support monitoring. Preliminary results from related ongoing research, in addition to existing indictor data, are provided to suggest that Gilbert Bay cod are locally adapted and that migratory Northern cod overlap spatially and temporally with the distribution of Gilbert Bay cod. Adapting the existing monitoring program, and related research, to focus on improving effectiveness of the MPA to meet conservation objectives could be warranted; however, changes could impact consistency of the long-term MPA monitoring program. Should management changes take place, continued consistent monitoring is needed to measure and evaluate whether the expected biological response is realized.

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TABLES

Table 1. Research sampling results and stewardship fishery data collected near Gilbert Bay from 1998 until 2016. Research sampling occurred in spring, usually near the beginning of June. The area of stewardship fishing is located in 2J, along the south coast of Labrador, including the area from Occasional Harbour in the North to Spear Harbour in the South. The 2016 fishery was managed on a weekly basis, and therefore a seasonal IQ is Not Applicable (NA) as in previous years. The fishing season was still open in 2016 when these data were gathered, therefore the reported landings for 2016 could change if additional landings are reported.

Year	Sampling Period	Research CPUE	IQ (kg)	# Harvesters	Reported Landings (t)	Fishing Season
1998	June 1-10	5.8	1,125	17	8.1	Sep 24 - Oct 16
1999	May 20 -June 2	3.4	1,082	11	12.1	Jul 8 - 31, Sep 13 - Oct 16
2000	June 10-22	3.1	3,810	3	0.6	Jun 16 - 19, Sep 11 - Nov 30
2001	May 29 - June 7	3.4	3,810	2	0.9	Jul 9 - Sep 30, Nov 5 - 30
2002	June 11 - 19	4.2	3,810	9	5.7	Jul 30 - Oct 13
2003	June 4 - 10	2.4	0	0	0.0	No Fishery
2004	June 1 - 8	4.4	0	0	0.0	No Fishery
2005	June 1 - 19	3.3	0	0	0.0	No Fishery
2006	June 1 - 10	3.2	1,361	10	0.0	Aug 16 - Sep 22
2007	June 1 - 10	2.1	1,134	19	17.7	Jul 23 - Aug 4
2008	June 2 - 12	2.2	1,474	21	17.6	Sep 8 - Oct 6
2009	June 2 - 11	2.5	1,700	17	15.0	Sep 7 - Oct 1
2010	June 2 - 11	1.6	1,700	16	13.3	Aug 28 - Oct 1
2011	June 2 - 11	3.4	1,700	11	9.4	Aug 29 - Sep 25
2012	June 7 - 13	2.0	1,700	13	11.7	Sep 7 - Sep 28
2013	June 6 - 12	1.3	2,268	10	11.3	Sep 1 - Sep 21
2014	June 3 - 8	0.4	2,268	10	15.3	Aug 31 - Sep 20
2015	June 4 - 8	0.6	2,268	7	13.6	Aug 30 - Sep 19
2016	June 1 - 8	1.1	NA	11	28.4	Aug15 - Dec 16

FIGURES

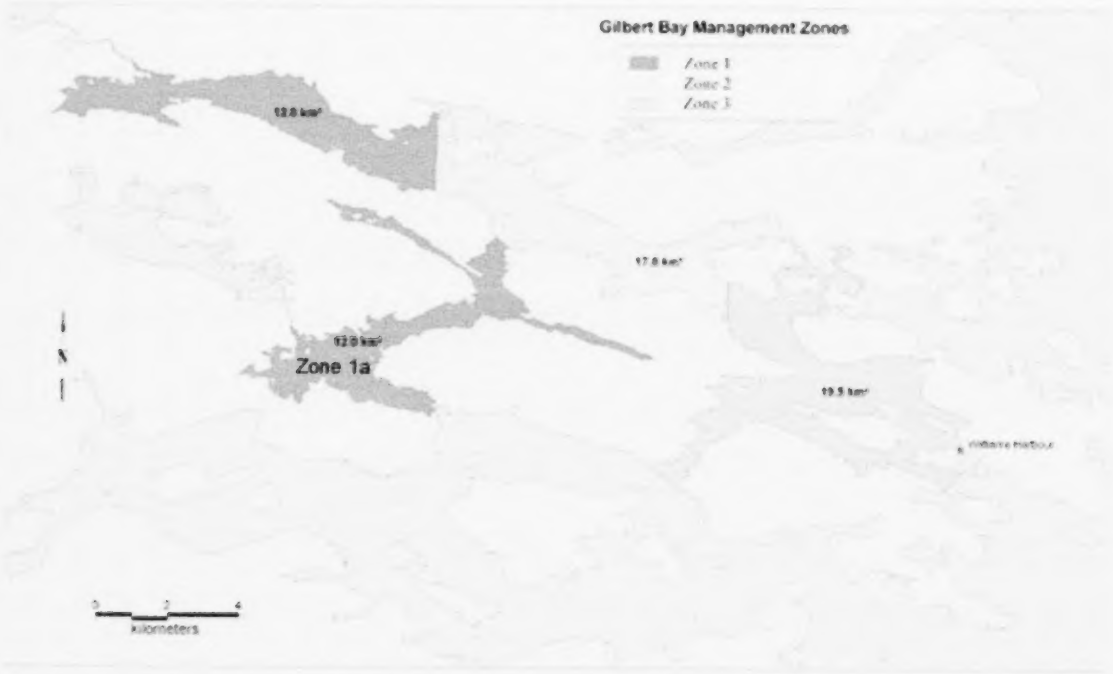


Figure 1. Map of the Gilbert Bay MPA and management zones. Zone 1 in red, is divided into two parts, the southern part is referred to as zone 1a.

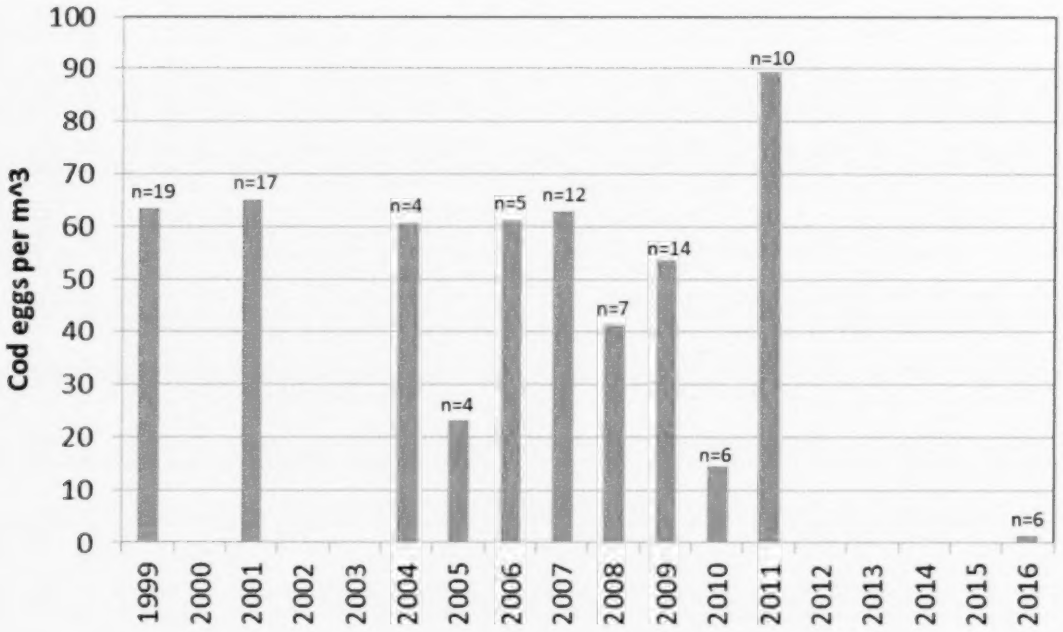


Figure 2. Density of cod eggs sampled in Gilbert Bay zone 1a in early June. Sampling consisted of 15 minute plankton net tows using a 1 m diameter ring net with 333 um mesh. Several different depths were sampled at least once during each year, including 2 m, 5 m, and 7 m. Egg densities were typically highly variable and depth of highest egg densities varied with the amount of water column salinity stratification, with highest egg densities occurring just below the surface fresh water layer. The number of samples taken each year is indicated on the plot. Several years of collected samples were not processed including 2000, 2002, and 2003, 2012-15. The obviously low density of cod eggs sampled in 2016 was the lowest on record.

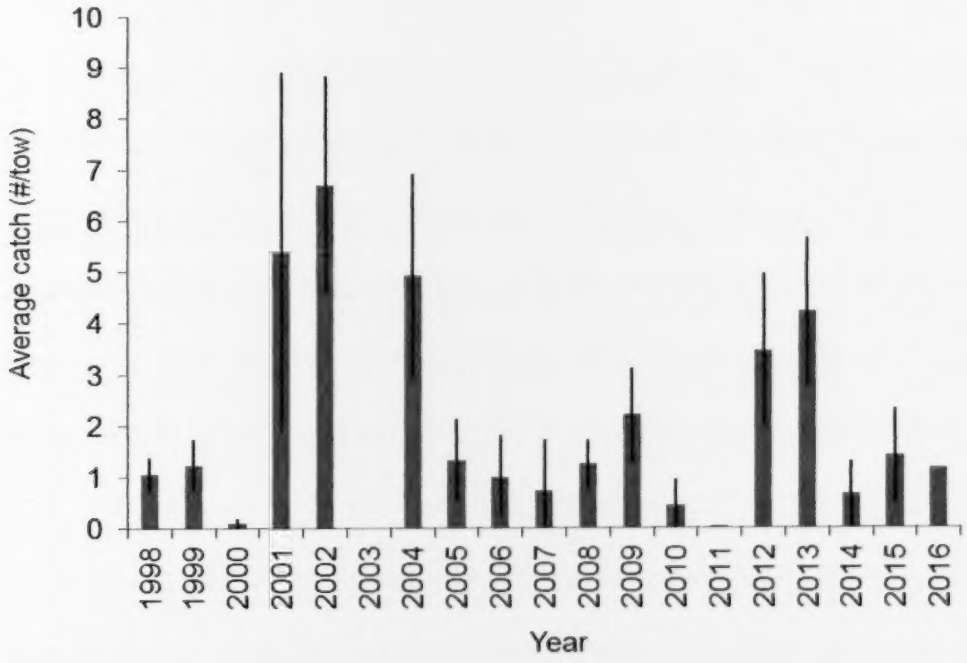


Figure 3. Average number of pelagic juvenile cod (G. morhua and/or G. ogac) that was sampled in Zone 1a during daytime sampling conducted in early August. 95% confidence bars are indicated. Typically, N=20-30 plankton tows per year are conducted.

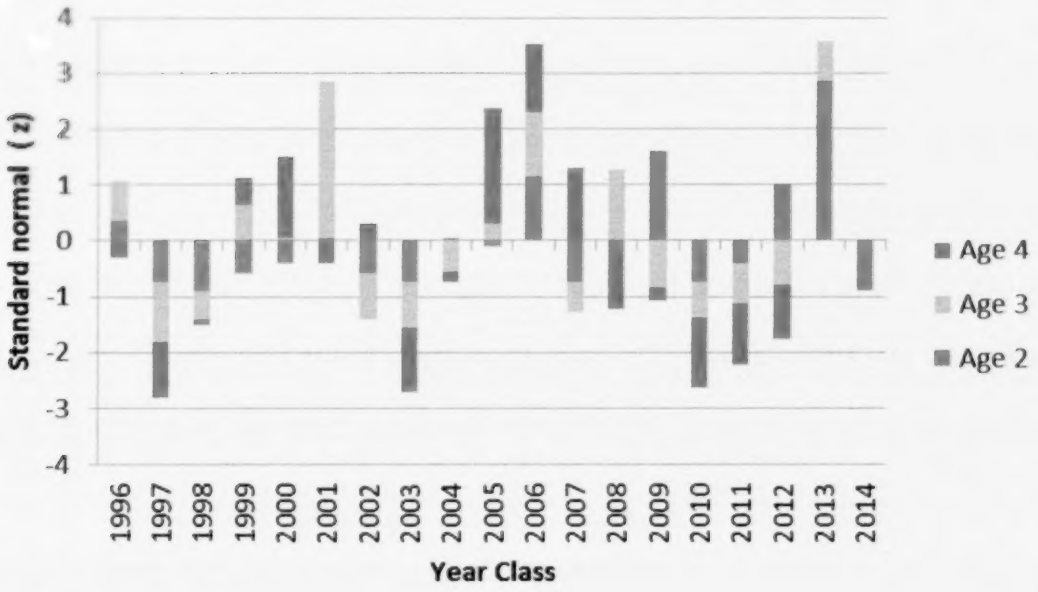


Figure 4. Year class strength estimates based on relative abundance of fish ages 2-4, extracted from length frequency distributions standardized by effort. Numbers of fish at age were assigned to year class and the datawere standardized to a mean of 0 and standard deviation of 1. Abundance at age then contributed to indicate the relative strengh of a year class. Positive values represent stronger year classes and negative values represent weaker year classes. Years 2013 and 2014 do not have data availbable for fish ages 4 and ages 3 and 4 respectively, because these ages will not be sampled until 2017 and 2018.

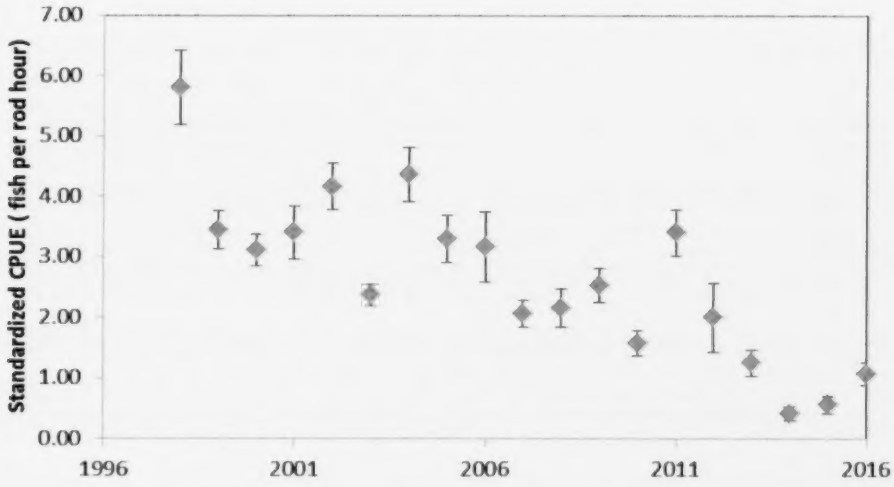


Figure 5. CPUE, standardized by average annual effort, of cod sampled per rod hour of fishing effort in MPA zone 1A (The Shinneys). All sizes of cod area included.

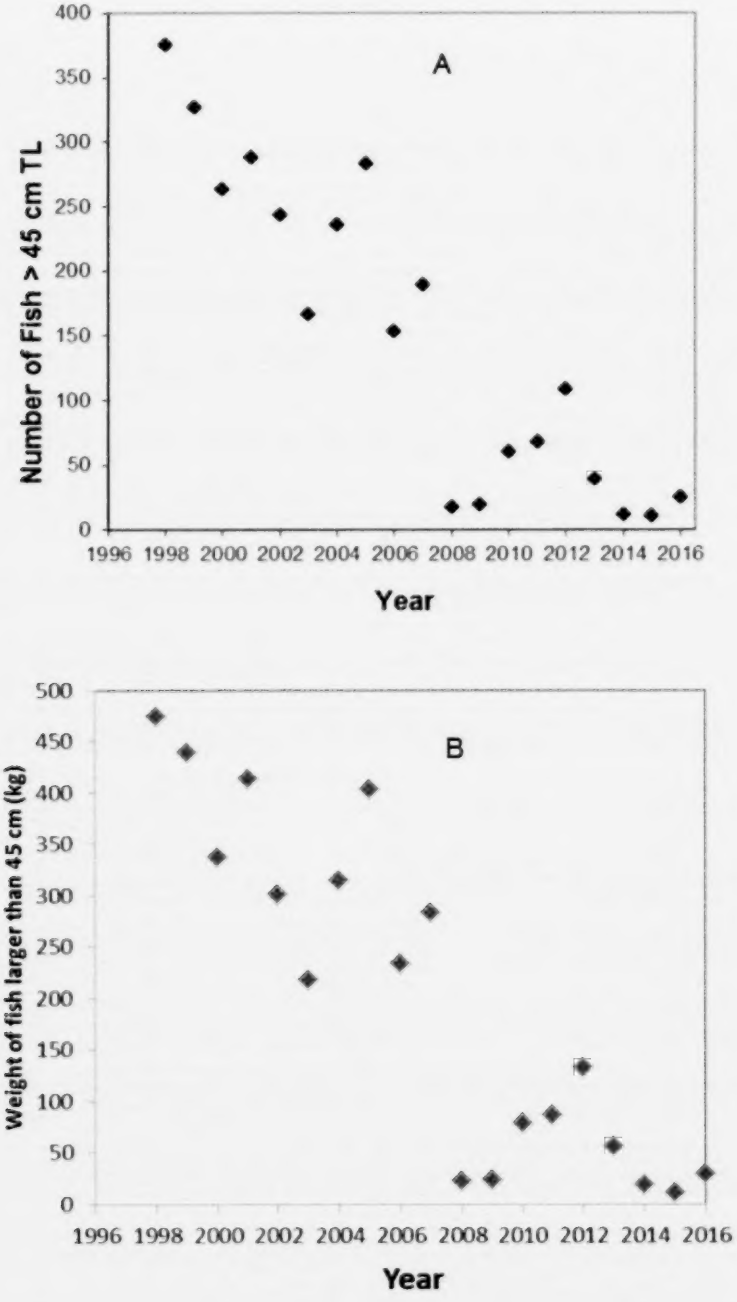


Figure 6. Standardized number of commercial sized (> 45 cm) Atlantic Cod sampled in MPA zone 1A (A), and weight of commercial sized (> 45 cm) Atlantic Cod sampled in MPA zone 1A (B).

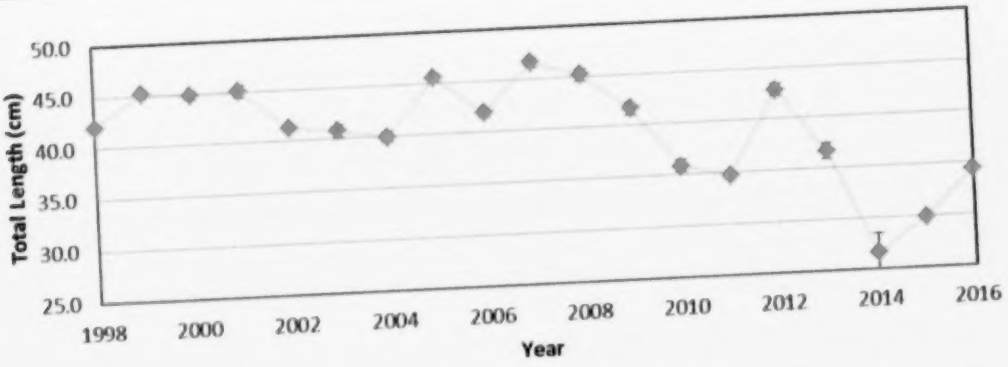


Figure 7. Mean fish length (TL) sampled in MPA zone 1A during spring sampling. The decline in average size since 2007 is most noticeable in 2014. The size at maturity is approximately 35 cm TL.

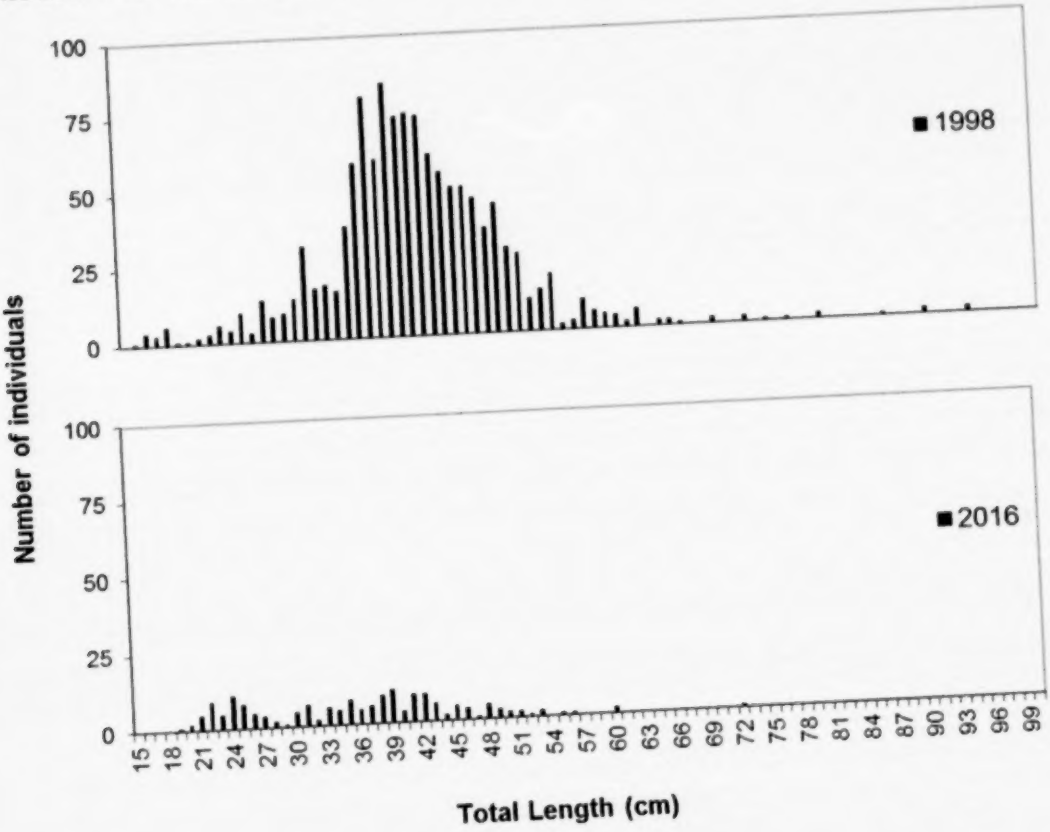


Figure 8. Length frequency distributions, standardized by fishing effort, sampled in MPA zone 1a during the first and most recent year of sampling, 1998 and 2016 respectively. Modes representative of year classes are particularly difficult to distinguish at sizes larger than 35 cm, which is also typically when Gilbert Bay cod first reach sexual maturity. Commercial size of Atlantic Cod is approximately 45 cm TL.

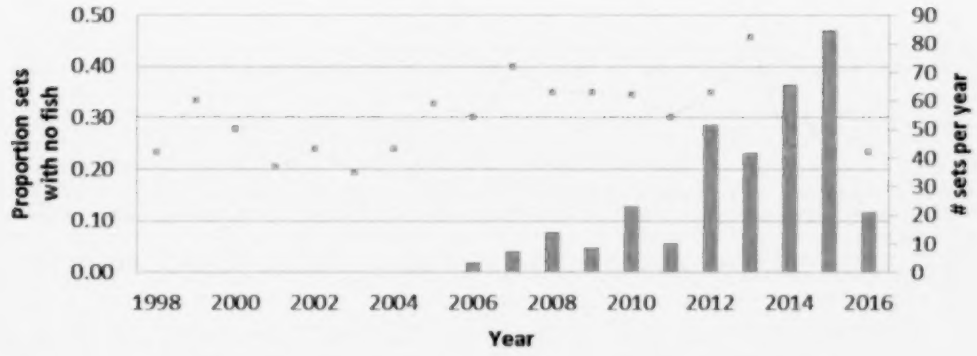


Figure 9. Bars and the primary y axis indicate the proportion of fishing sets in MPA zone 1A that were sampled for a minimum of 30 minutes without capturing any fish. There has been a general increase in the number of zero-catch sets since 2006. The number of sets conducted in each year, indicated by the line and secondary y-axis, has remained between 35 and 80 sets per year.

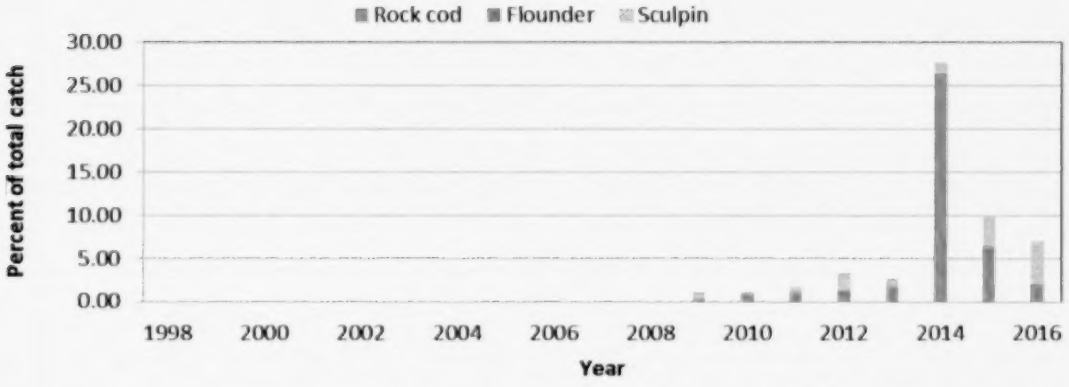


Figure 10. Fish community changes measured as a percentage of total catch represented by species other cod, including rock cod, flounder, and sculpin. No species other cod were caught by the Gilbert Bay monitoring program in MPA zone 1A prior to 2009. Since then, other species have consistently represented an increasing proportion of the total catch.

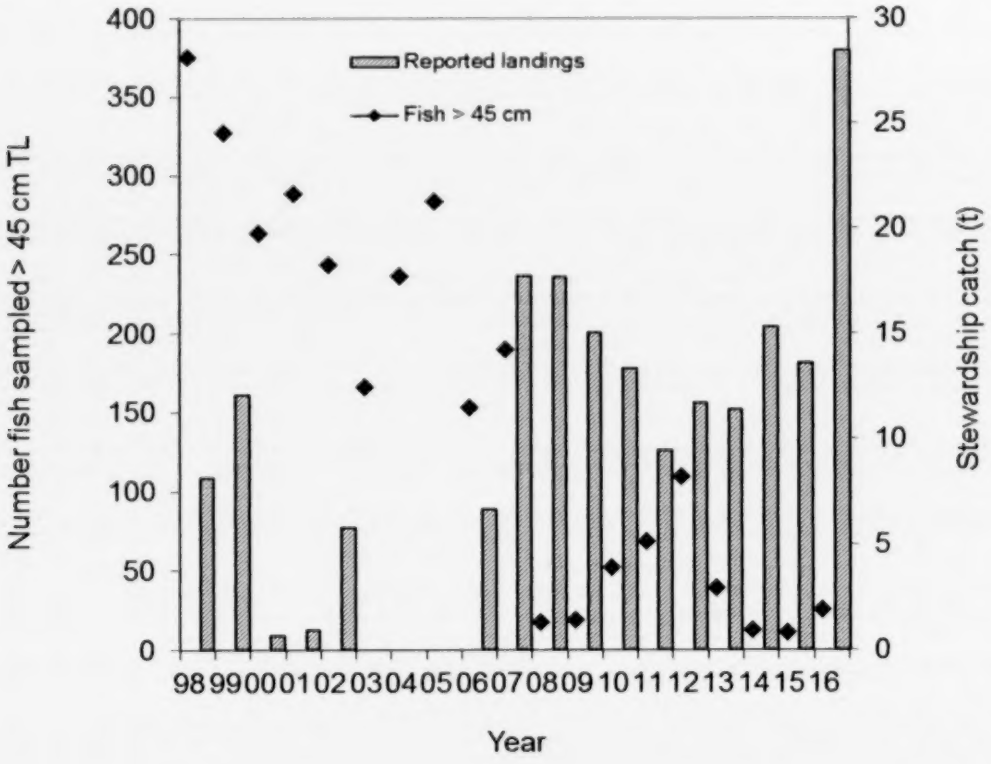


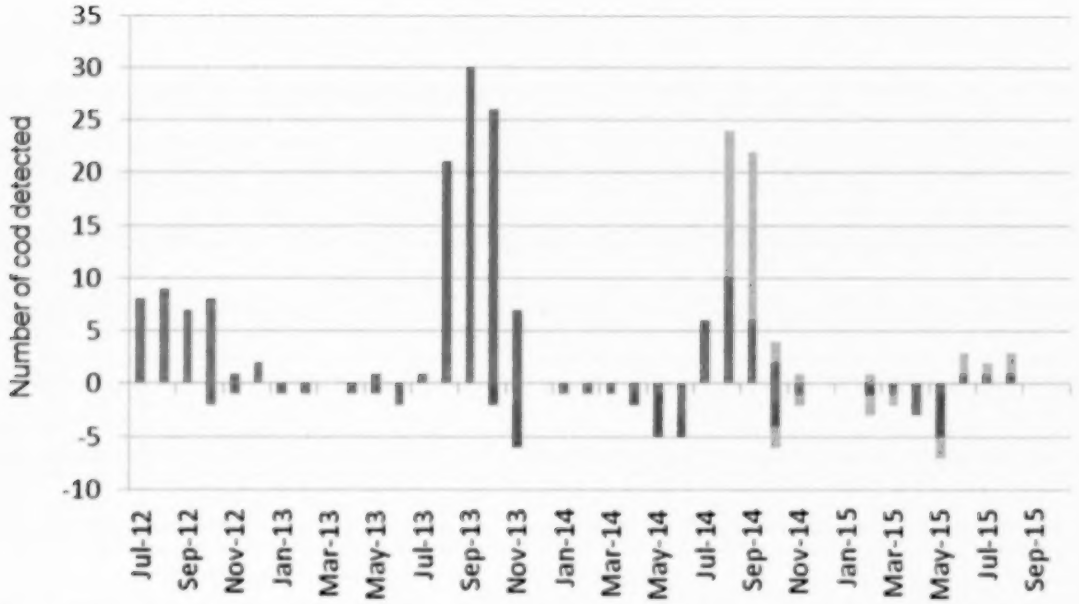
Figure 11. Standardized number of commercial sized Gilbert Bay cod sampled during spring research sampling in MPA zone 1A (Blue dots primary Y axis), and reported landings from the stewardship fishery. Timing of the fishery is indicated in Table 1.

APPENDIX A: SUPPORTING RESEARCH

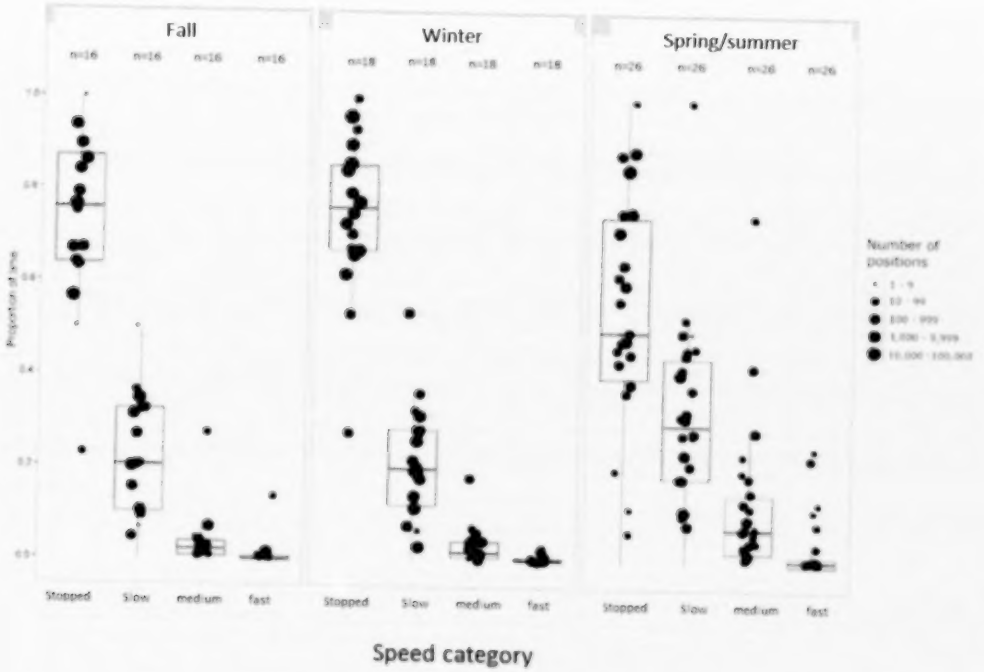
This appendix includes information from ongoing research associated with the Gilbert Bay MPA, including selected relevant results from two ongoing studies pertaining to the migration of Northern cod (Appendix Fig. 1) that overlap with Gilbert Bay cod during summer months, and an overwintering study of Gilbert Bay cod (Appendix Fig. 2). Acoustic Telemetry has been conducted in Gilbert Bay since 1998 and these data have provided near continuous information regarding movement patterns of Gilbert Bay cod. This has included movement information related to the home range of Gilbert Bay cod and timing of migration to areas outside the MPA (Morris and Green 2014; Morris et al. 2014). Such research is an important part of MPA management and has continued in recent years, although it is not used as a specific monitoring indicator; rather telemetry studies are conducted to address targeted research questions. Telemetry research since the last monitoring review has focused on the migration of Northern cod that occupied areas surrounding the boundaries of the Gilbert Bay MPA and on the fine scale movement patterns of Gilbert Bay cod overwintering behaviour.

Several Northern cod occurring in the vicinity of Gilbert Bay during July until October were discovered to migrate offshore to the Hawk Channel area in winter. These telemetry data confirm that Northern cod overlap in habitat usage with Gilbert Bay cod. It also suggests that Northern cod are available in the inshore areas during late summer and fall, when a majority of Gilbert Bay cod have returned to the MPA after summer migrations to the coast. Interestingly several fish that were detected some 125 km offshore (Hawk channel) were also detected a considerable distance (~175 km) south of Gilbert Bay, near the Grey Islands during early summer and again during fall (Morris et al. unpublished data).

Recent telemetry research has provided detailed positioning of several Gilbert Bay cod during winter, to characterize overwriting behaviour. It found that Gilbert Bay cod overwinter at an average depth of 10 m during February and March and move considerable distances (within the same general area) underneath winter ice at sub-zero temperatures throughout the winter. Movements of cod were similar during fall (temperatures above 0°C) compared to winter (temperature less than 0°C). These behavioural data suggest that Gilbert Bay cod cope with sub-zero temperatures very well. This information, in addition to other information pertaining to spawning location and timing, and shallow water local residency, suggests that the population exhibits local adaptation to their environment which is important to Atlantic Cod biodiversity.



Appendix Figure 1. Detections of Atlantic cod tagged immediatley outside the Gilbert Bay MPA boundary. Colours represent year of tagging, Blue=2012, Red=2013, and Green=2014. Positive values indicate inshore detections near Gilbert Bay, and negative values indicate offshore detections. Inshore detections occur from July until November, and offshore detections occur from November until July.



Appendix Figure 2. Movement data based on positional telemetry data of tracked cod in MPA zone 1a. The speed of fish movements were divided into four categories during three periods, including fall before temperature dropped below 0˚C, during winter at sub-zero temps, and during spring after temperatures increased above 0˚C. Temperature was measured at 10-12 m depth which is the preferred depth of Gilbert Bay cod during winter.